ESA/Hubble & NASA

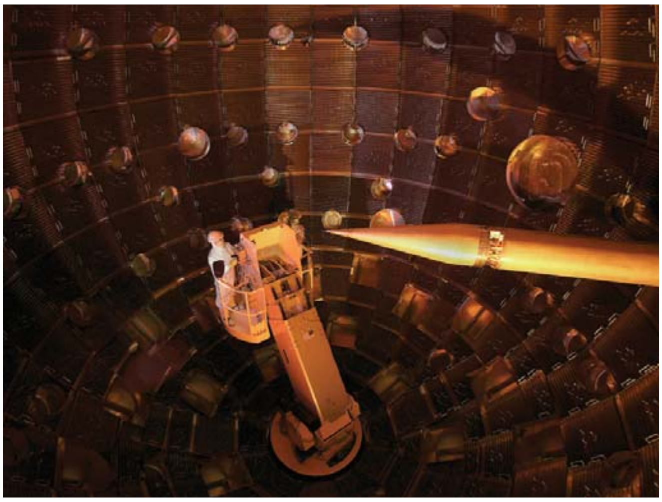
Shooting for the stars

Using the world's largest and most energetic laser, scientists in the USA have been replicating the extreme temperature and density conditions inside stars to better understand the process of element formation within them.

The laser is known as the National Ignition Facility (NIF), and it's located at the Lawrence Livermore National Laboratory in California. The NIF building is so enormous that three football fields could fit inside it, and much of it is devoted to the laser and target area section. Here, almost 40 000 optics – including lenses, laser glass slabs, mirrors and frequency conversion crystals – precisely guide, reflect, amplify and focus 192 laser beams. A beam travels about 1 500 m in a few millionths of a second to arrive at a 3 mm-wide target in the centre of a 10 m-wide chamber. The tiny target is a gas- or ice-filled capsule typically containing hydrogen or helium isotopes, and when blasted with up to 1.8 million joules of energy it implodes, resulting in an extremely hot and dense core of plasma (freely moving ions and free electrons), where nuclear reactions occur.

The NIF was designed for experiments that create similar conditions – temperatures of 100 million degrees Celsius and pressures 100 billion times that of the Earth's atmosphere – to those found in a detonating nuclear device, with the aim of ensuring the safety of the USA's nuclear weapons stockpile. August 2019 marked NIF's 10th year in operation, and by then some 2 700 experiments, called 'shots', had been conducted by scientists working on nuclear weapons issues. However, about 8% of overall shot time is set aside for basic science experiments that probe the inner workings of stars, planets and materials.

Dr Maria Gatu Johnson, a research scientist at the Massachusetts Institute of Technology (MIT), is the principal investigator for a project examining stellar nucleosynthesis, or element formation, in the interior of stars. The American Physical Society (APS) recently named Dr Gatu Johnson the winner of the Katherine E. Weimer Award, which recognises outstanding plasma science research by a woman physicist in the early stages of her career. Her award acceptance lecture formed part



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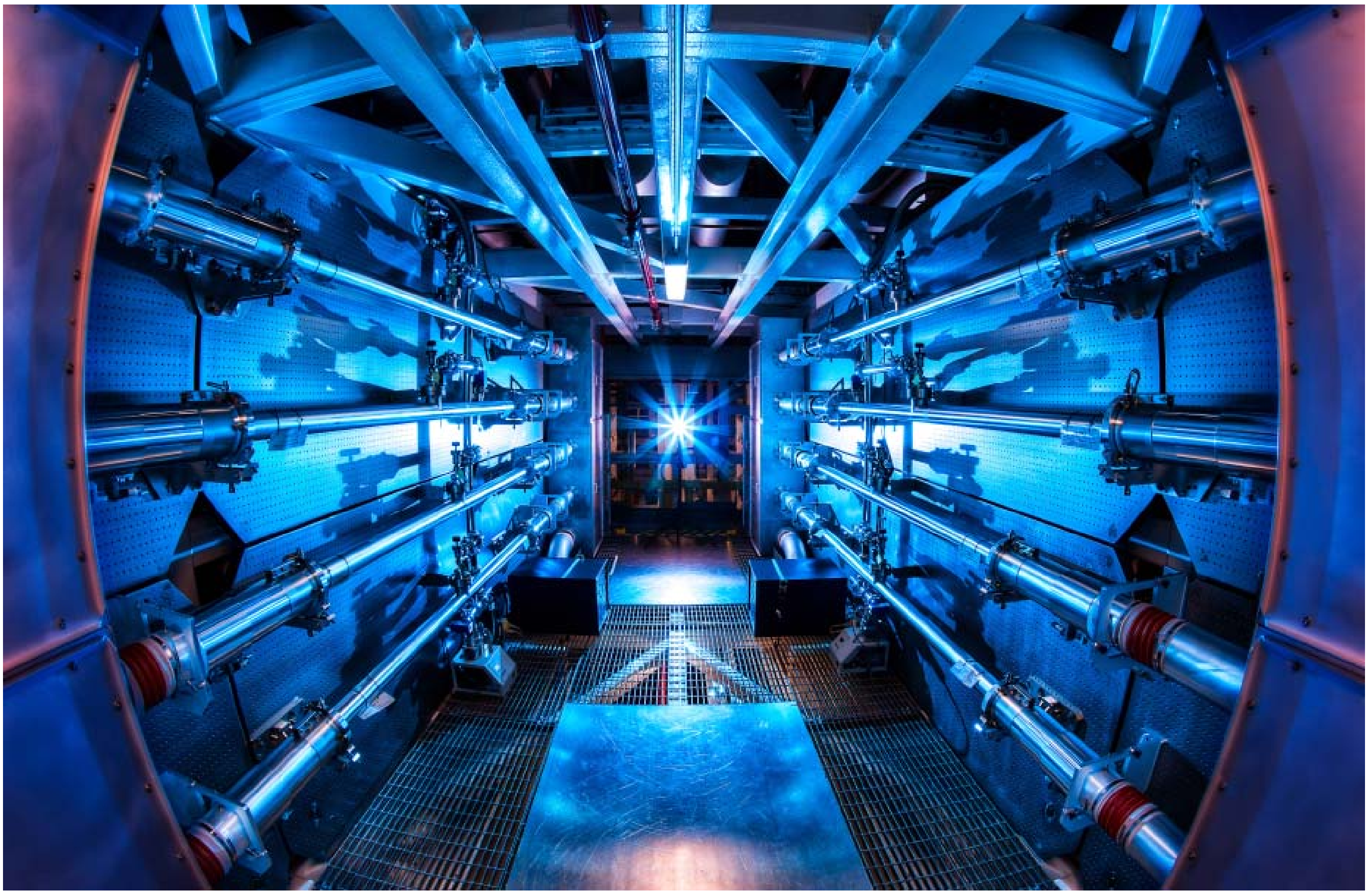
Technicians on a service lift inside the target chamber. The pencil-like structure on the right is the target positioner, which holds the tiny target.



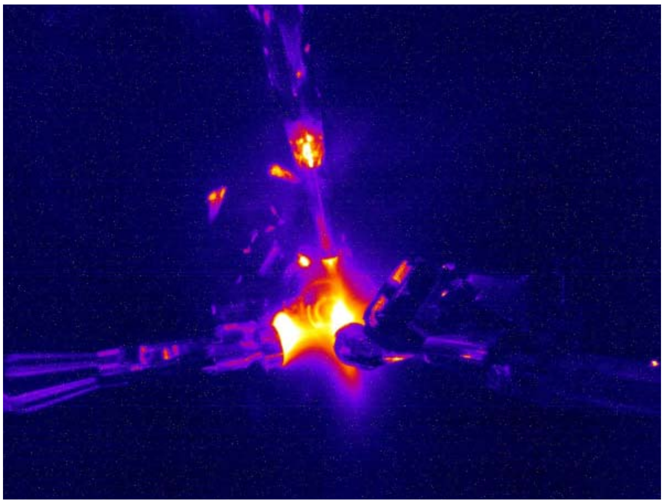
Damien Jemison/LLNL

The preamplifiers of the National Ignition Facility are the first step in increasing the energy of laser beams as they make their way toward the target chamber.

of the APS Division of Plasma Physics meeting held in Fort Lauderdale, Florida, in October 2019. In it, Dr Gatu Johnson spoke about the ongoing NIF experiments to study fusion reactions of helium-3, a light helium isotope.

Previously, she had explained that these involve the 'proton-proton 1' chain of nuclear reactions at the beginning of the stellar nucleosynthesis cycle. In the core of the Sun and other stars, nuclear fusion converts hydrogen into helium, and a small amount of matter is turned into energy in the process.

"It starts with just the protons in the nucleus of regular hydrogen atoms," Gatu Johnson said. "They fuse to



Don Jedlovec/LLNL

'Shot-time' image from a NIF experiment simulating stellar nucleosynthesis, with $^3He+^3He$ fusion reactions happening in the white-hot, dense centre.

form deuterium (as one of the protons is converted to a neutron), and then deuterium can fuse with a proton to form helium-3. The helium-3 particles once produced fuse to form helium-4 (also known as an alpha particle), and generate two protons which will go through the cycle again."

"This is the most significant energy-producing step in the Sun – $^3He+^3He$ reactions actually produce almost half the energy in the proton-proton 1 chain – so it's very critical to know the rate of that reaction."

Dr Gatu Johnson reported on how protons from the $^3He+^3He$ reaction have been observed in these experiments at a range of conditions. "Surprisingly, the preliminary results show that at lower temperatures, relatively more protons are seen with higher energy than with lower energy," she said.

These results will allow scientists to add important constraints on theoretical calculations of this complicated reaction, and to estimate the probability of the $^3He+^3He$ reaction happening. There will be one more round of experiments, currently planned for February 2020, where Dr Gatu Johnson plans to better characterise the temperatures reached in the star-like conditions.

Adapted from press releases issued by the Lawrence Livermore National Laboratory (https://lasers.llnl.gov/) and the American Physical Society (http://www.aps.org).

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